Characteristics of Carbon Doped GaN Films Grown by Molecular Beam Epitaxy

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Recent development of the growth techniques of Ⅲ-nitrides such as GaN, InGaN and AlGaN has resulted in the successful fabrication of GaN-based optical devices such as blue/ultraviolet LD and LED. In the fabrication of these devises, magnesium is widely used as p-type dopant. However, magnesium has several disadvantages in the following respects: high vapor pressure and low sticking coefficient, its tendency for surface segregation and diffusion and low ionization ratio at room temperature. Group-Ⅳ elements act as acceptor or donor in GaN depending on whether they are located on gallium sites or nitrogen sites. Among group-Ⅳ elements, carbon has much interest for p-type dopant because it preferentially occupies nitrogen site due to its similarity to nitrogen in atomic radius and electronegativity. However, various characteristics of carbon doped GaN films have been reported in the previous studies [1-3]. In this paper, characteristics of carbon doped GaN films grown by MBE using RF-excited nitrogen plasma and NH_3 as nitrogen source are reported.

Sapphire (0001) was used as substrate. Two types of nitrogen sources were employed in this experiment: one is RF-excited nitrogen plasma (RF-plasma assisted MBE) the other ammonia (ammonia-MBE). In the RF-plasma assisted MBE, CH_4 was employed as dopant gas and two methods of CH_4 gas supply were studied as follows: one is the direct supply of CH_4 gas to the GaN film surface during growth aiming at the cracking of CH_4 at the surface, and the other is that after cracking of CH_4 in the RF-plasma nitrogen source. In the ammonia- MBE, solid carbon was used for doping to prevent the nitrogen deficiency at the growing film surface due to the supply of uncracked CH_4 gas. Solid carbon was sublimed using electron beam gun. In the both growth methods, non-doped GaN layer of 500Å thick was grown before carbon doped GaN film growth to guarantee the similar nucleation condition of all the samples.

In the RF-plasma assisted MBE, carbon doping was studied at the CH_4 flow rate of 0.5 sccm - 1.5 sccm. High resistivity GaN films were obtained by the direct supply of CH_4 gas to the film surface during GaN growth. The resistivities of the grown films were ranged from $9\times10^3\Omega$cm to $4\times10^4\Omega$cm, with proportional to the CH_4 gas flow rate. This means that, in contrary to the previous reports [1,2], carbon forms deep acceptor level and acts as source of compensation in n-type GaN. J.B.Webb et al. also studied the carbon doping using CH_4 into the saddle field ion gun in ammonia-MBE and

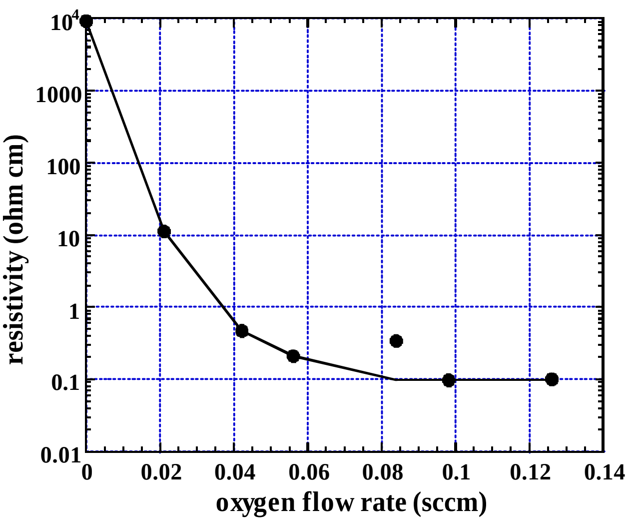

Fig.1. Oxygen flow rate dependence of the resistivity of co-doped GaN films.
(CH4 flow rate : 0.5sccm)

found that thermal cracking at the film surface was insufficient to induce carbon incorporation. However, in our study, carbon could be incorporated into the film by the direct supply without cracking, indicating that cracking of CH_4 molecule adsorbed on the growing GaN film surface is enhanced by the nitrogen plasma irradiation. Furthermore, higher carbon incorporation was realized by the supply of CH_4 gas through RF-nitrogen plasma source. SIMS analysis revealed that one - two higher orders of magnitude of carbon could be incorporated into the film by the cracking of CH_4 using RF-nitrogen plasma source. The resistivities of the grown films were higher than $10^6\Omega$cm. So, co-doping [4] was tried for obtaining p-type GaN films with low resistivities. Figure 1 shows the oxygen flow rate dependence of the resistivity of the co-doped GaN films grown using oxygen as n-type dopant. As shown in Fig.1, resistivity of the grown film decreases with the oxygen flow rate. However, p-type GaN film could not be obtained in this study.

Carbon doped GaN films grown by ammonia-MBE exhibited lower resistivities (0.02Ωcm – 0.4Ωcm) compared with those grown by RF-plasma assisted MBE, though cathode luminescence of the grown films showed typical features of carbon doped GaN films with intense yellow band luminescence [1,5] as shown in Fig.2. SIMS analysis showed that not self-compensation [1] but residual impurity of oxygen in the grown film, which is originated from H_2O included in the ammonia gas, at the carrier concentration of $\sim 10^{18}/cm^3$ is the origin of lower resistivities.

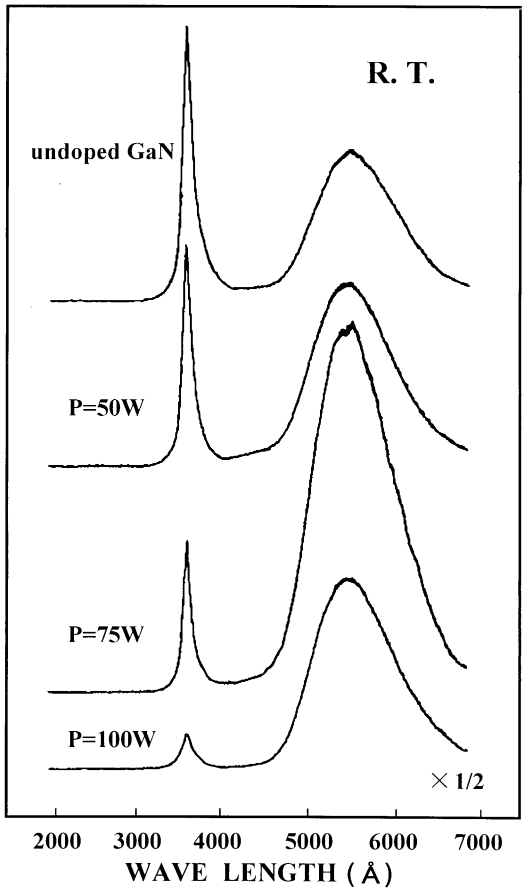

Fig.2. CL spectra obtained from carbon doped ammonia-MBE grown GaN films P denotes the input power of electron beam gun for carbon sublimation.

In conclusion, characteristics of carbon doped GaN films grown by MBE were investigated. Carbon doped GaN films with reistivities higher than $10^6\Omega$cm could be obtained by RF-plasma assisted MBE using CH_4 as dopant gas. This implies that carbon forms deep acceptor level and acts as source of compensation in n-type GaN.

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